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SUSPENDED SOLIDS MONITOR

John W. Liskowitz, et al

American Standard, Incorporated

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By

John W. Liskowitz
Newark College of Engineering
Newark, New Jersey 07102

Gerald J. Franey
Joseph Tarczynski
American Standard Inc.
New Brunswick, New Jersey 08903

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Project Officer

Allyn St. C. Richardson
U.S. Environmental Protection Agency
Region I
Boston, Massachusetts 02203

NATIONAL ENVIRONMENTAL RESEARCH CENTER
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

Both of these objectives require instrumentation to measure pollution and its effects, and to control the processes used to prevent discharge of pollutants to the environment and to recover reusable resources. The instrument described herein is expected to find application for all of these needs.

A. W. Breidenbach, Ph.D.
Director
National Environmental
Research Center, Cincinnati

ABSTRACT

A method for measuring concentration of suspended solids in liquid media, based on depolarization of backscattered polarized light, has been developed and instrumented. Feasibility studies and field evaluation of the instrument, using sewage influent, effluent and sludge, showed that there is a specific relationship between concentration of solid particles and polarization ratio. It was also shown that the relationship is independent of size distribution and density of particles, color of particles or solution, sludge consistency, velocity, and build-up of solids on the optical window. The field evaluation results indicate that this instrument provides a continuous instantaneous *in situ* measurement of suspended solids concentrations in combined sewers and other wastewater flows.

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SECTION I

CONCLUSIONS

1. The feasibility study indicates that using the depolarization measurement to monitor concentration of suspended solids in sewage samples gives more closely repeatable results than standard gravimetric methods, and correlates well with them.

2. Suspended solids concentrations ranging from a few mg/l to at least 5000 mg/l can be measured using the depolarization technique.

3. The relationship between the polarization ratio and concentration of suspended solids in sewage samples has been shown to be substantially invariant for the range of particle size and density encountered in sewage.

4. The relationship between the polarization ratio and concentration of suspended solids is unaffected by sample source (industrial, domestic sewage, treatment plant influent, effluent or sludge).

5. Depolarization measurements are valid indicators of suspended solids concentration in the presence of organisms and aggregates generally found in sewage sludge.

6. Neither rate of flow of the sewage past the optical window nor buildup of solids deposits on the optical surfaces affect the polarization ratio measurement, provided that light intensity is above the response threshold of the detectors.

7. In the sewage treatment plant, at Perth Amboy, New Jersey, which receives a substantial flow and diversity of industrial wastes, a specific relationship was found between suspended solids concentration and polarization ratio, which held for combined - sewer influent, storm water overflow, and plant effluent.

8. The instrument can be used to monitor suspended solids in treatment plant influent and effluent, in the presence of contamination such as oil or soap suds, which affect the gravimetric determinations or in highly colored solutions.

9. The data indicate that a higher degree of repeatability is attained by depolarization measurements than by gravimetric measurements.

10. The present model will operate in any type of sewage environment. It requires a 120 VAC power source. During measurements the present instrument requires attention for adjustments in electronics. A design change recommended in the RECOMMENDATIONS Section should eliminate this problem.

11. Linearization of the response function of the suspended solids monitor over several decades of suspended solids concentration shows promise if use is made of the logarithm of the polarization ratio and an optical path longer than 5.5cm (2.17 inches).

SECTION II

RECOMMENDATIONS

Since resources available under this contract were exhausted after very limited field testing of the model, a program of continued testing is recommended. This program would have two major objectives; to establish the optical measurements as a valid indicator of suspended solids under as wide a range of conditions (waste parameters, ambient light, time since maintenance. etc.) as possible, and to determine the optimum design parameters for instruments tailored to operate in specific ranges of suspended solids concentration and environmental conditions.

Following this study (and contingent upon a favorable evaluation of its results) a further development should be undertaken, using the new information produced by the study and incorporating three changes first suggested by the Environmental Protection Agency Project Officer when reviewing design of the present model:

1. In place of the mechanical chopper, use an electronically modulated light source, such as a sinusoidally-modulated or pulse-modulated gas discharge tube.

2. Eliminate the separate measurement of background illumination and the analog computation necessitated thereby, by AC coupling the light sensor and pulse amplifier. This also eliminates troublesome sensor drift problems, permits operation of the sensor photodiodes in the photoconducting mode rather than the narrow-dynamic-range photovoltaic mode, avoids the need for manual adjustment to changing ambient light levels, and provides substantial advantages in reliability, size, and cost.

3. Use the polarization ratio $\frac{E_{\parallel} - E_{\perp}}{E_{\parallel} + E_{\perp}}$ as the measure, rather than degree of depolarization $E_{\perp}/E_{\parallel}$ as was used in earlier work. As detailed in Section VI, the logarithm of this polarization ratio should relate linearly to suspended solids concentration. Further theoretical and empirical linearization effort, as needed, should be included in the next development.

This further development will provide an instrument that can be installed in collection lines or at the plant to monitor in-situ the suspended solids concentration in municipal sewage influents and effluents and in combined storm sewer overflows. This will provide instantaneous intelligence signals that can be used to automate and control waste treatment operations and regulate and minimize combined storm sewer overflows.

Field evaluation of this instrument should be carried out using

a system such as the test facility developed by FMC Corporation, Santa Clara, California (1), where the concentration of suspended solids can be regulated and defined accurately. Field evaluation of the monitor in actual waste streams using grab sampling techniques does not provide the representative samples to which the monitor is continuously responding.

Fiber glass filters rather than membrane filters should be used for the gravimetric determination of suspended solids concentrations in waste streams when correlating this determination with the readout of the suspended solids monitor. The use of membrane filters can lead to errors in the gravimetric determination. The membrane filters were observed in a recent investigation (2) to remove both suspended and dissolved solids; whereas, the fiber glass filter removed only the suspended solids.

As an accessory to the suspended solids monitor, the possibility exists that a differential refractive index measurement can be developed to monitor in-situ the dissolved solids (organic plus inorganic) on a continuous basis. This differential instrument used in conjunction with the suspended solids monitor can further characterize the waste stream by providing a continuous measurement of total solids in a waste stream.

SECTION III

INTRODUCTION

A novel method, based upon the depolarization of scattered light, has been developed in our laboratories for the rapid and continuous determination of the concentration of particles in suspensions. This approach has been shown to respond to a greater concentration range of particles and is less dependent on particle size than the commonly used transmission and light scattering techniques (3). A polarization ratio serves as a measure of the degree of depolarization of scattered light. This ratio is readily determined by the measurement of the intensity of scattered radiation passing through a polarizing prism with its optical axis perpendicular ($E_\perp$) and parallel ($E_\parallel$) to the plane of incident polarized light (see Figure 1). The ratio of intensities, $\frac{E_\parallel - E_\perp}{E_\parallel + E_\perp}$ represents the polarization ratio.

In a solution containing particulate matter, incident light scattered by the individual particles (primary scattering) is in turn rescattered by other particles. This phenomenon is known as multiple scattering. It is known that as the concentration of the particulate matter in solution is increased, multiple scattering also increases.

Thus, the fraction of backscattered light which has been multiply scattered should increase with concentration of scattering particles.

It is possible to devise an optical system, using polarization techniques, to measure the degree of multiple scattering. This consists of a collimated source of plane polarized light illuminating the suspension to be measured, and a collimated light sensor "looking" at a zone of illuminated suspension, accepting light which has been scattered through a deflection angle of close to 180 degrees, say 170 degrees. The sensor is located so that the plane of this deflection beam is perpendicular to the plane of polarization of the incident light, as shown in Figure 1. The sensor is equipped with a plane polarizing device, permitting measurement of the energy components of the light it receives in the polarization planes parallel to the incident polarization plane ($E_\parallel$) and perpendicular thereto ($E_\perp$). With this optical configuration, light which has been scattered only once (primary scattering) will not exhibit any energy in the $E_\perp$ component; that is, there will be no depolarization. Multiple scattering, however, through various deflection angles in random planes aggregating 170 degree in the required plane, will be depolarized (4).

The measurement parameter used herein is $(E_\parallel - E_\perp)/(E_\parallel + E_\perp)$, which defines the polarization ratio, P. At very low concentration of suspended particles, virtually all the light reaching the sensor will be from primary scattering, and multiply-scattered illumination of the sensor will be negligible. As these conditions are approached, $E_\perp$ will approach zero, and therefore the ratio P will approach unity.

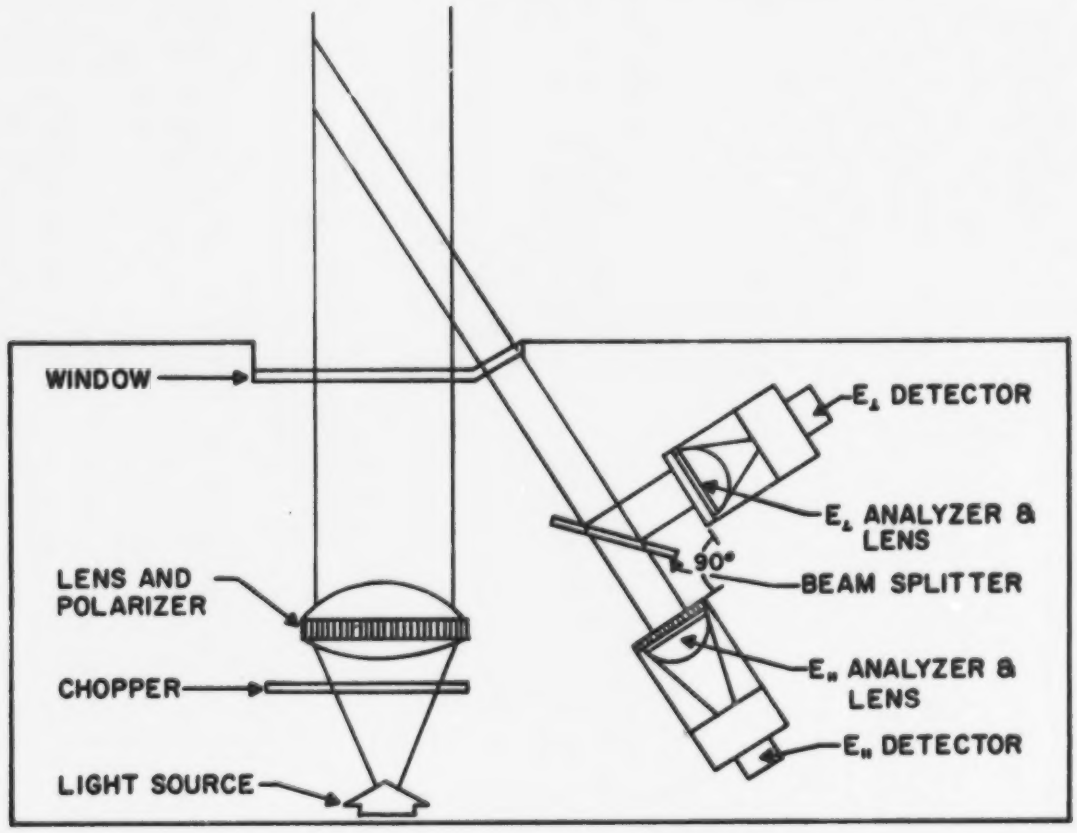

FIGURE 1 - OPTICS DIAGRAM

The other extreme, approached at very high concentrations of suspended solids, is complete randomization by multiple scattering with $E_\perp$ approaching equality to $E_\parallel$, and therefore P approaching zero.

There may be some preference for a parameter which increases monotonically with increasing suspended solids, and we may define a depolarization ratio D, equal to 1-P, which will traverse the range 0 to 1 as suspended solids concentration changes from zero to infinity. This parameter, however, is unsuited for linearization by the logarithmic relationship proposed below.

Without undertaking rigorous treatment of the theory involved, we propose that the decrement dP in degree of polarization resulting from an incremental increase in solids concentration dC should be proportional to the remaining degree of polarization P. That is,

$$\frac{dP}{dC} = -kP \qquad (1)$$

where k is a positive constant of proportionality. This has the familiar form of a logarithmic relationship.

$$\frac{dP}{P} = -kdC \qquad (2)$$

$$\text{Ln}P = -kC + \text{const.} \qquad (3)$$

Evaluating the const., when P = 1, then C = 0, and therefore const. = 0, and we are left with

$$-\text{Ln}P = kC \qquad (4)$$

or

$$-\text{Log}\ P = \frac{k}{2.3}C \qquad (5)$$

The experimental results give some evidence of linearity of the relationship between -Log P and C. Further work as recommended will confirm or refine these assumptions.

Object of Investigation

The first objective of the investigation was to verify the feasibility of the measurement of depolarized backscattered radiation as a method of determining concentration of solid particles in an aqueous suspension. The second objective was to construct a prototype instrument which would continuously monitor suspended solids in flowing sewage systems.

In pursuing these objectives, some unexplored parameters were investigated to prove feasibility. The instrument was designed to accommodate these parameters. Factors considered in feasibility, and in design, will be discussed briefly.

SECTION IV

DESIGN OF EXPERIMENTS

Parameters Investigated

Previous depolarization measurements (3) on model hydrosol systems proved that the degree of depolarization is dependent upon the ratio of the refractive index of the solid to that of the medium and upon the volume concentration of particles in suspension. Correlation of depolarization with weight concentration is obtained by measuring the density of the solids. Selection of the wavelength of incident radiation so that it is comparable to, or smaller than, the size of the smallest particles to be measured in the sewage will reduce the effect of particle size upon the determination.

Thus devising a technique using the depolarization of backscattered polarized radiation for monitoring the amount of the suspended solids in combined sewer overflows and other storm or wastewater flows involves as significant parameters the size distribution of the suspended solids, and the density, color variations, and refractive index ratios of particles and mediums. These are examined in sewage samples for their effect on depolarization. The effect of optical surfaces coated with deposited solids and the effect of flow on the measurement, also must be considered.

Prototype Design

The prototype includes means for remote changing of the optical path length from 2 cm (0.8 inches) to 30 cm (12 inches) while the suspended solids monitor is in a given sewer environment. Thus, an optical path length can be selected that provides maximum sensitivity for monitoring the concentration of suspended solids for a specific environment.

The prototype also allows the depolarization measurements to be performed in the presence of ambient light radiation. The effect of ambient radiation on measurements is eliminated by chopping the incident illumination to the sample. The receiver optics in the prototype measures the energy resulting from both the backscattered and ambient radiation, and from ambient radiation alone. The backscattered radiation energy is found by difference.

The prototype also permits the angular acceptance of the receiver unit to be regulated; so that the levels of ambient radiation entering the receiver can be controlled. The magnitude of the ambient radiation which may result from sunlight in open channels when low concentration of suspended solids are monitored, can drive the photodiodes in the receiver unit into saturation. Hence, means to reduce the levels of ambient radiation that enters the detector are necessary.

Analytical Procedures

Since the effect of particle size and distribution on depolari-

zation was not known at the time this study was undertaken, the analysis of the suspended solids in sewage was carried out by filtration and weighing of the solids on 10μ and 0.3μ membrane filters. Particles less than 0.3μ will be mainly smaller than half the wavelength of incident radiation used and for the most part will not be detected either by the gravimetric technique using a 0.45μ membrane filter as recommended by the EPA or by the suspended solids monitor.

It was found that the dissolved solids in sewage could be determined directly on the unfiltered sample. A linear correlation was found between the refractive index of the solution and the dissolved solids. A differential refractometer was used, since the difference in the refractive index from that of pure water was in the fourth and fifth decimal place.

SECTION V

LABORATORY EVALUATION OF FEASIBILITY

Feasibility Study (Phase I)

The investigations comprising Phase I were conducted in the laboratory, using actual sewage in place of the idealized test suspensions of preproposal experiments. Two sewage sources were utilized; Middlesex Sewage Authority's treatment plant, Middlesex, New Jersey, where influent is composed of 50 per cent industrial and 50 per cent domestic sewage, and Bernardsville, New Jersey Sewage Plant handling 100 percent domestic sewage. The suspended solids concentration range covered in these experiments was from 30 mg/1 up to 4800 mg/1. The suspended solids in the influent and effluent were from 30 mg/1 to about 400 mg/1, and the concentration in the sludge samples ranged from about 1300 mg/1 to 4800 mg/1.

The results of the depolarization measurements in the laboratory show that the backscattered polarization decreased with increasing suspended solids concentration regardless of the source of the sewage samples. The relationship between polarization and concentration of suspended solids was found to be the same whether the sample was influent, effluent or sludge. A Bernardsville activated sludge sample diluted with effluent to reduce its solids concentration below 400 mg/1 exhibited the same polarization ratio as the influent and effluent at the same concentration of suspended solids (Figure 2). The Bernardsville plant effluent was used for dilution because it contains low solids concentration (30 mg/1 to 40 mg/1) and it did not cause flocculation of the suspended solids in the sludge. When water was used as a diluent, flocculation of the particles occurred. The sharpest decrease in the polarization ratio with concentration occurred below a concentration of about 1000 mg/1, (Figure 2). These measurements were made when the detectors were directed at the incident beam in the center of 11 cm (4.33 inches) I.D. sample cell. Above 1000 mg/1, there was a more gradual depolarization with increasing concentration. At these high concentrations, complete attenuation of the incident beam was observed before it reached the center of the sample cell. At the low end of the concentration range, the instrument responded satisfactorily to concentrations as low as 20 mg/1. These samples were taken from the Bernardsville, New Jersey, sewage plant effluent. Overhead laboratory illumination had no effect on polarization measurements.

Repeatability and Scatter

The scatter in experimental data, especially at high suspended solid concentrations as shown in Figure 2, is probably caused more by lack of repeatability in the gravimetric determination of suspended solids in sewage as well as the inability to obtain the samples to

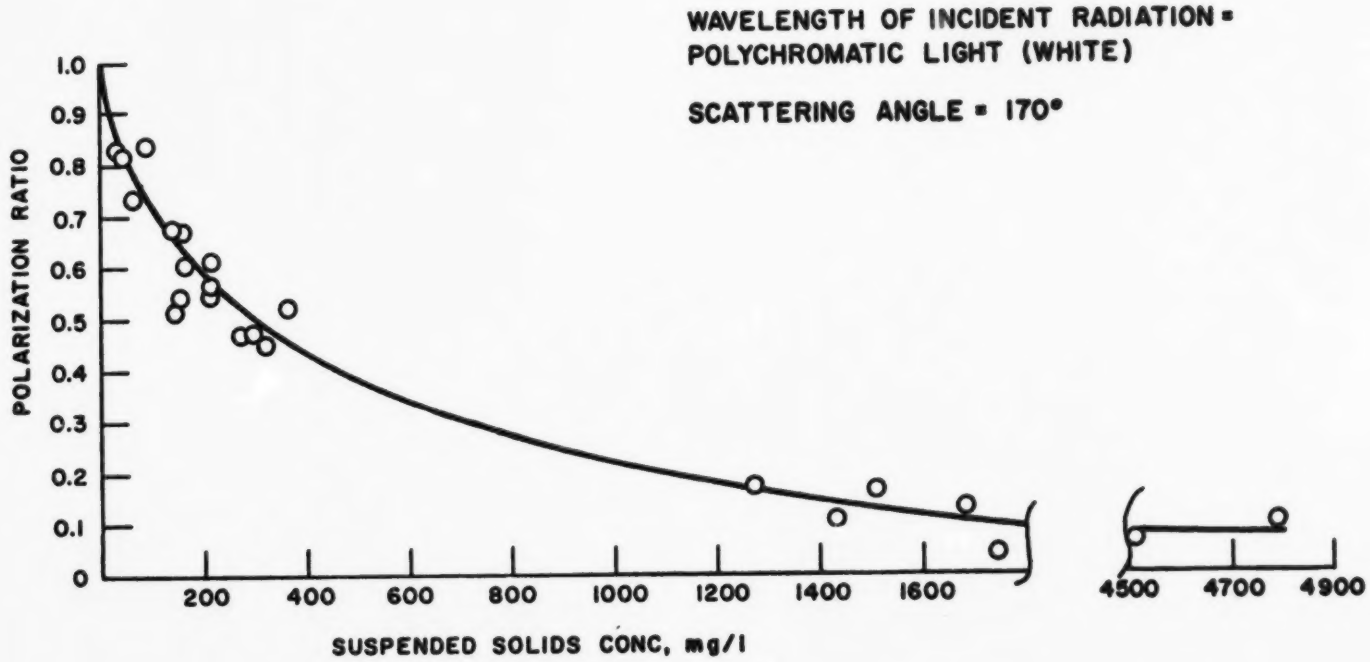

FIGURE 2 - POLARIZATION RATIO vs GRAVIMETRIC SUSPENDED SOLIDS MEASUREMENT, 5.5 cm OPTICAL PATH

which the instrument is responding than by the variability in polarization measurements or their correlation with actual suspended solids in the size range they measure. As a basis for comparison, conventional approaches, such as the measurement of the intesity of backscattered radiation indicated poor correlation with the gravimetric determination on samples taken from the Middlesex Treatment Plant (see Figure 3). The data in Figures 2 and 3 were obtained on the same samples. A check of the reproducibility of the gravimetric determination showed a 16 per cent range in the results of three separate determinations on the same influent sample. Also, the suspended solids instrument provides an instantaneous readout whereas the gravimetric determination of suspended solids on a number of samples required filtration times of some ten to twelve hours. Marked variations in the correlation between the readout and the gravimetric determinations was encountered in such cases.

Optical Path Length

Reducing the optical path length for the polarization measurements from 5.5 cm (2.17 inches) to 2.3 cm (0.9 inches) resulted in a more gradual decrease in polarization with increasing concentrations below 1000 mg/l (see Figure 4). The above findings indicate that reducing the optical path length from 5.5 cm to 2.3 cm will lead to an increase in the sensitivity of polarization measurements in the concentration range above 1000 mg/l. However, the relationship between the polarization ratio and concentration of suspended solids above 1600 mg/l, using the shorter optical path lengths, was not examined; during the measurement period the suspended solids content of sludge at both Middlesex and Bernardsville was low. Additional data to fill this gap are needed.

Linearization of Relationship

Replotting the data in Figure 2 according the Equation 5 (page 6) reveals the existence of a linear relationship for the concentration range 300 mg/l - 1700 mg/l using an optical path of 5.5 cm (see Figure 5). Similarly, the data in Figure 3 shows linearity for the concentration range 600 mg/l - 1700 mg/l, using an optical path of 2.3 cm (see Figure 6). Increasing the optical path length increases the range over which the logarithm is linear (compare Figure 5 with Figure 6). These findings suggest that the results of the depolarization measurements may be linearized at lower concentrations by using optical paths longer than 5.5 cm.

Sample Characteristics

Analysis of the Middlesex and Bernardsville influents indicated marked variations in the particle density and size distribution (see Table I).

The solids in Sample No. 1 separated into two layers in the density gradient column. These ranged from 1.20 to 1.40 g/cc and from 1.50 to 1.59 g/cc. The solids in the remaining samples formed

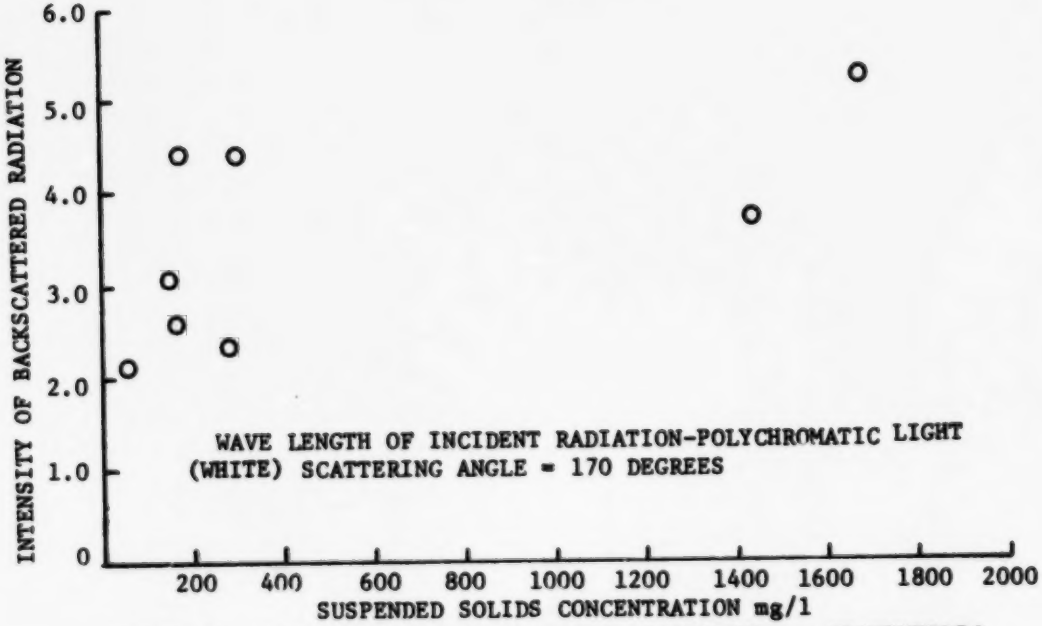

FIGURE 3 - INTENSITY OF BACKSCATTERED RADIATION vs GRAVIMETRIC SUSPENDED SOLID MEASUREMENT, 5.5 cm OPTICAL PATH.

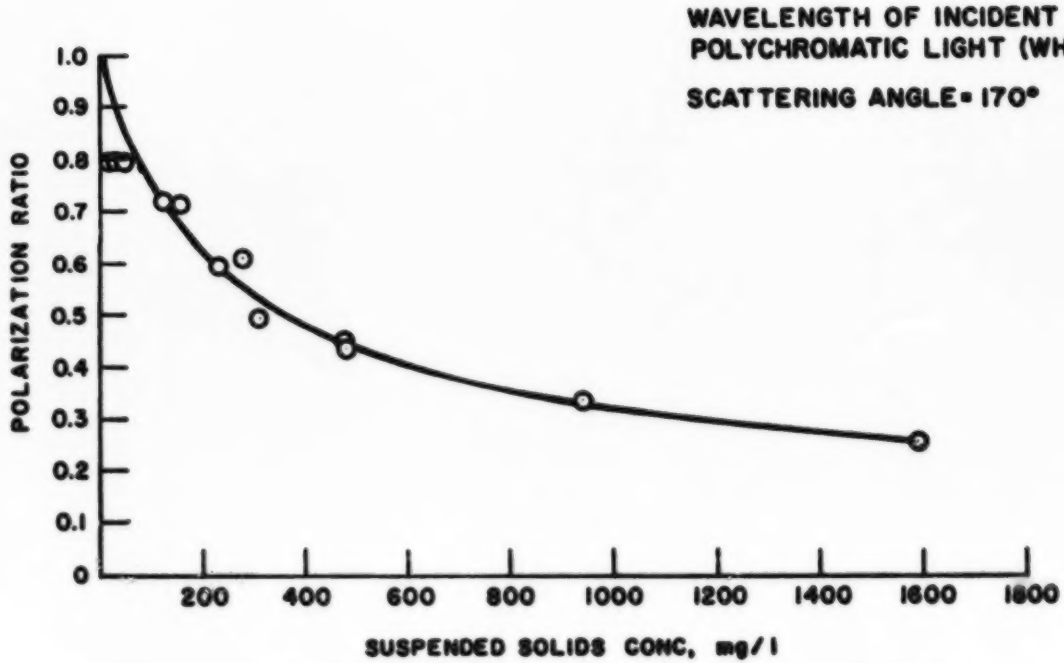

FIGURE 4 - POLARIZATION RATIO vs GRAVIMETRIC SUSPENDED SOLIDS MEASUREMENT, 2.3 cm OPTICAL PATH

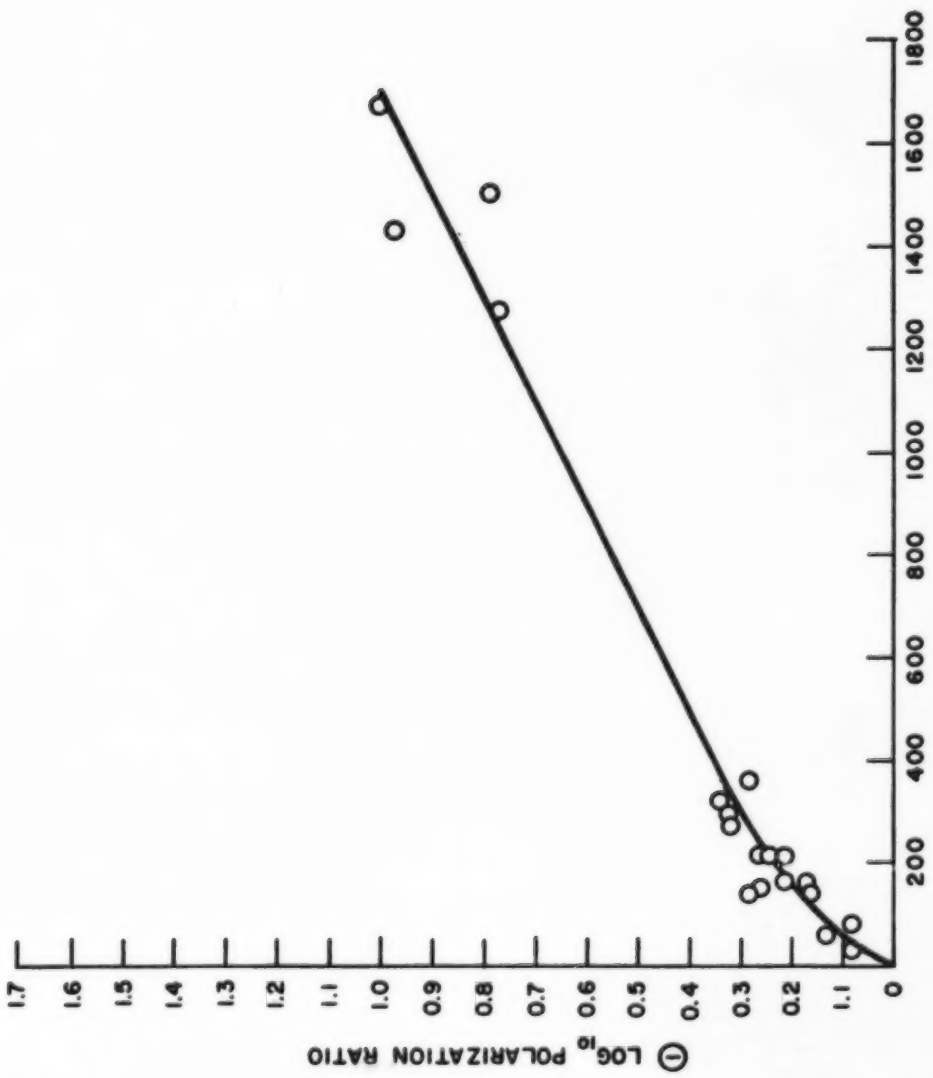

FIGURE 5 - LOG POLARIZATION RATIO, 5.5 cm OPTICAL PATH

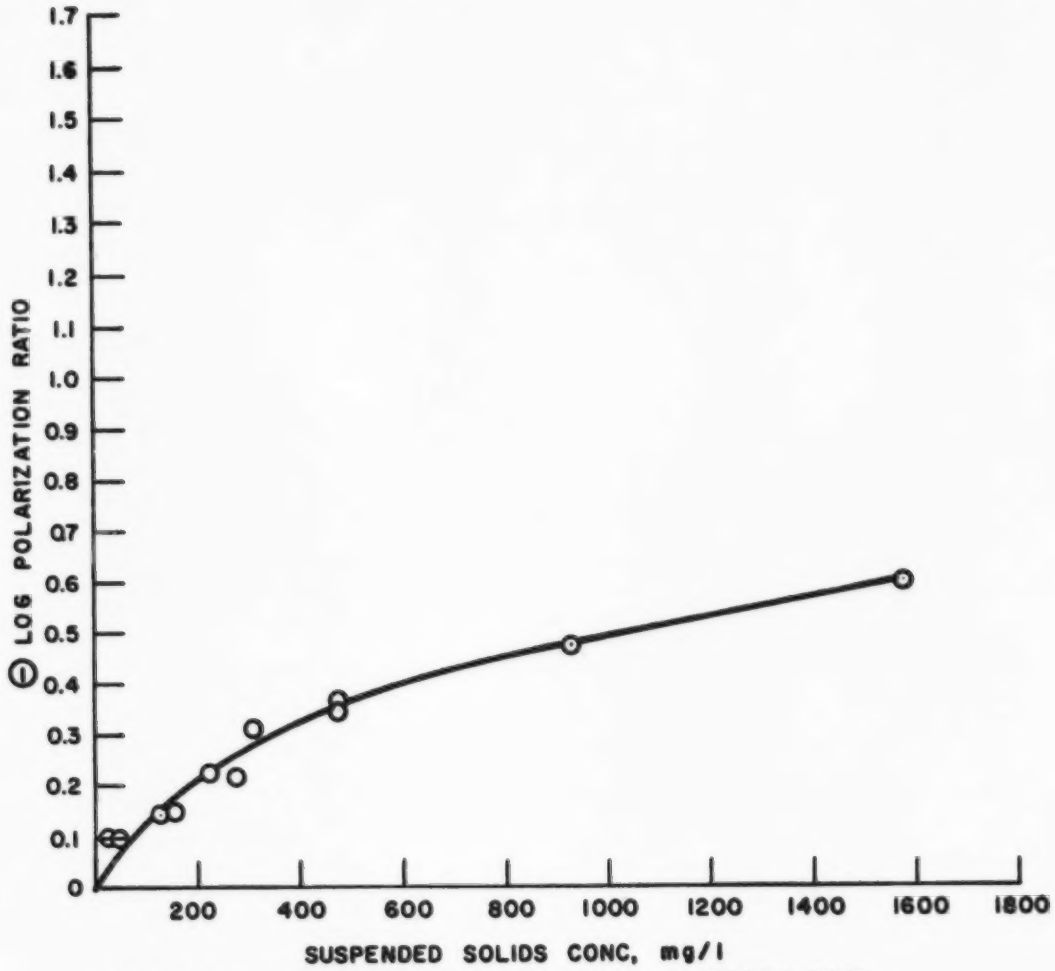

FIGURE 6 - LOG POLARIZATION RATIO, 2.3 cm OPTICAL PATH

TABLE 1

CHARACTERIZATION OF BERNARDSVILLE AND MIDDLESEX INFLUENTS

Sample No.	Source	Date Collected	Suspended Solid (mg/1)	Dissolved Solid (mg/1)	Density Range (g/cc)	Size Distributions
1	Middlesex	5/23/69	275	1733	1.20-1.40 1.50-1.59	13%>54μ 19%>44μ 68%>15μ
2	Middlesex	5/27/69	300	1133	1.52-1.66	6%>54μ 15%>44μ 54%>15μ
3	Middlesex	7/10/69	476	2236	1.14-1.39	10%>36μ 25%>26μ 38%>19μ
4	Bernardsville	7/15/69	228	435	1.56-1.65	18%>34μ 43%>24μ 58%>20μ

single layers that ranged in density from 1.52 to 1.66 g/cc. In comparison, a Middlesex influent sample collected on 5/15/69, not shown in Table I, also formed a single layer, but ranged in density only from 1.14 to 1.39 g/cc.

The color variation in these sewage samples was quite marked. The influent, effluent and sludge from the Middlesex plant ranged from light to dark brown; the influent and effluent from Bernardsville ranged from white to clear, and the activated sludge sample was black when tested in the laboratory. The wide range of color variations is indicated by the range of intensities of total backscattered radiation (Table 2), since color attenuates both the incident and scattered light.

Refractive Index Measures Dissolved Solids

The results of refractive index measurements on sewage samples indicate small differences between the sample and distilled water. A sample containing 1800 mg/l of dissolved solids exhibited a refractive index difference of only 3.7×10^{-4}. However, a linear relationship was found to exist between the concentration of total dissolved solids and increase in (organic plus inorganic components) refractive index of the sewage sample (Figure 7). The same relationship was found to exist, regardless of whether the sewage samples were collected from Middlesex or Bernardsville. The dissolved solids in the Middlesex and Bernardsville influent was analyzed to establish this relationship. The volatile portion was found to range from 19 to 31 percent (Table 3). The fixed portion of the dissolved solids was found by x-ray diffraction measurements to consist mainly of NaCl. Comparison of representative thermogravimetric curves obtained by heating Bernardsville and Middlesex influent indicates that organic constituents are similar (Figure 8). Both influents exhibited inflection points between 200 and 300°C and between 500 and 600°C. The light absorption spectra obtained for both influents are also similar. Absorption maxima were observed at 223 mμ and 275 mμ (see Figure 9). Further measurements on the influent and effluent of seven treatment plants located in New Jersey indicated that the same linear relationship exist between the refractive index and total dissolved solids concentration for a variety of waste streams (1). These measurements were performed directly on the waste samples and are uneffected by the presence of suspended solids. [The discovery that dissolved solids concentration in sewage can be estimated by differential refractometry is interesting. As an accessory to the suspended solids monitor, this method would provide for a measurement of dissolved solids.]

Deposits on Optical Surfaces

A slow and irregular rate of buildup of solids was observed on the surface of the beakers submerged in the activated sludge tank at the Bernardsville sewage plant. Six days were required before any significant deposits were observed. These deposits were distributed unevenly and covered only a small portion of the beaker's surface. Depolarization and backscattering intensity measurements on the Middlesex influent, using a beaker that was submerged for 42 hours, indicate that cleaning the beaker had no effect on either depolarization or the intensity of the total backscattered radiation (see Table 4). However, when the beaker was submerged for six days, the

TABLE 2

EFFECT OF COLOR ON TOTAL BACKSCATTERED LIGHT

Sample	Source	Date Collected	Total Backscattered Radiation Intensity (Millivolts)	Suspended Solids (mg/l)	Color of Suspension
Effluent	Middlesex	6/17/69	9.97	165	light brown
Influent	Middlesex	6/17/69	7.28	379	dark brown
Sludge from Clarrifloccs	Middlesex	6/17/69	10.83	4797	dark brown
Effluent	Bernardsville	6/13/69	2.41	37	clear
Influent	Bernardsville	6/13/69	6.43	206	white
Activated Sludge	Bernardsville	6/13/69	1.79	1516	black

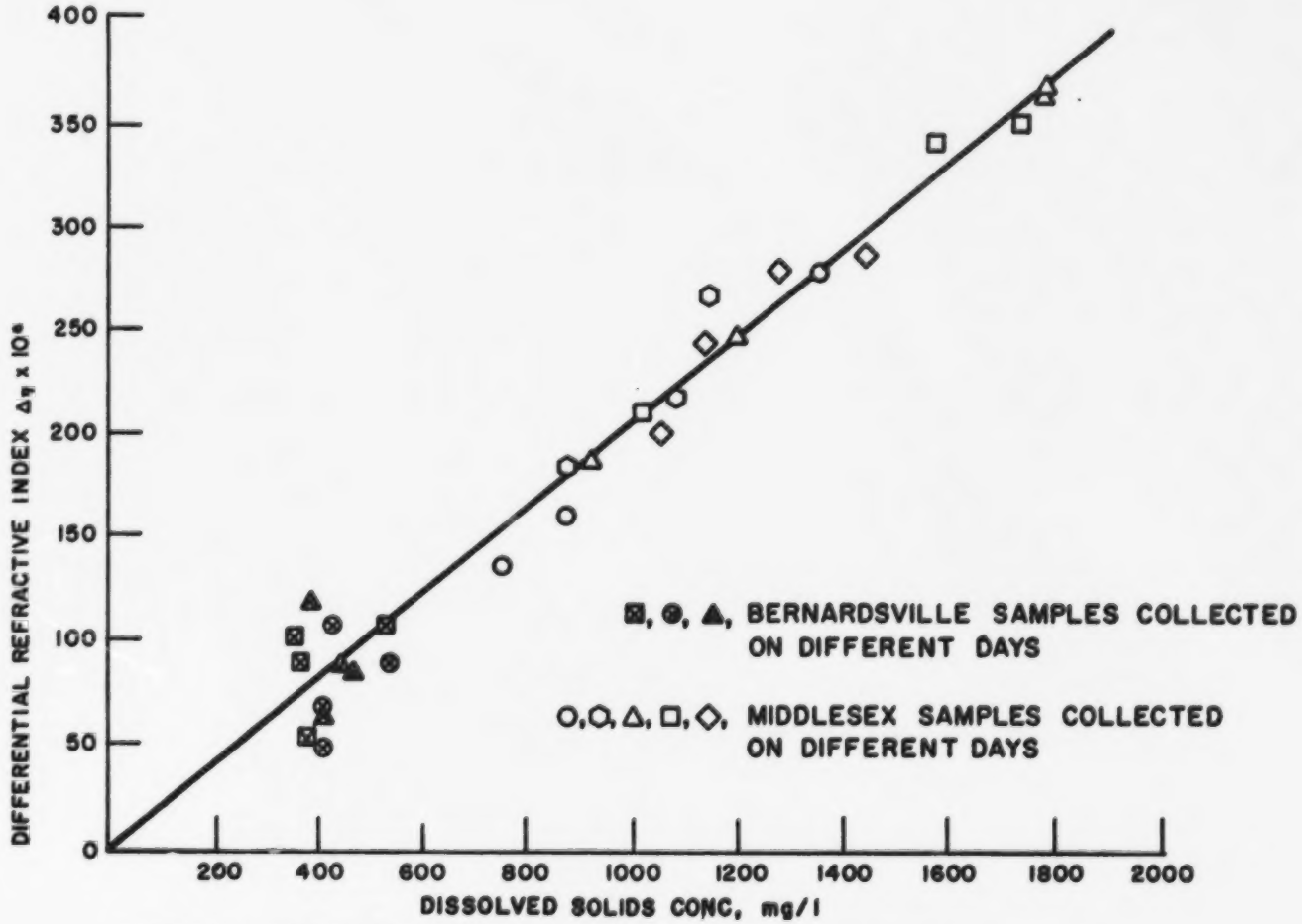

FIGURE 7 - REFRACTIVE INDEX vs DISSOLVED SOLIDS CONCENTRATION

TABLE 3

TOTAL AND VOLATILE DISSOLVED SOLIDS IN
BERNARDSVILLE AND MIDDLESEX INFLUENTS

Source	Date Collected	Dissolved Solids (mg/l)	Per Cent Volatile (By Weight)
Middlesex	7/10/69	2236	30.5
Bernardsville	7/15/69	435	24.9
Middlesex	7/17/69	1256	23.2
Bernardsville	7/22/69	287	19.5
Middlesex	7/22/69	904	31.0

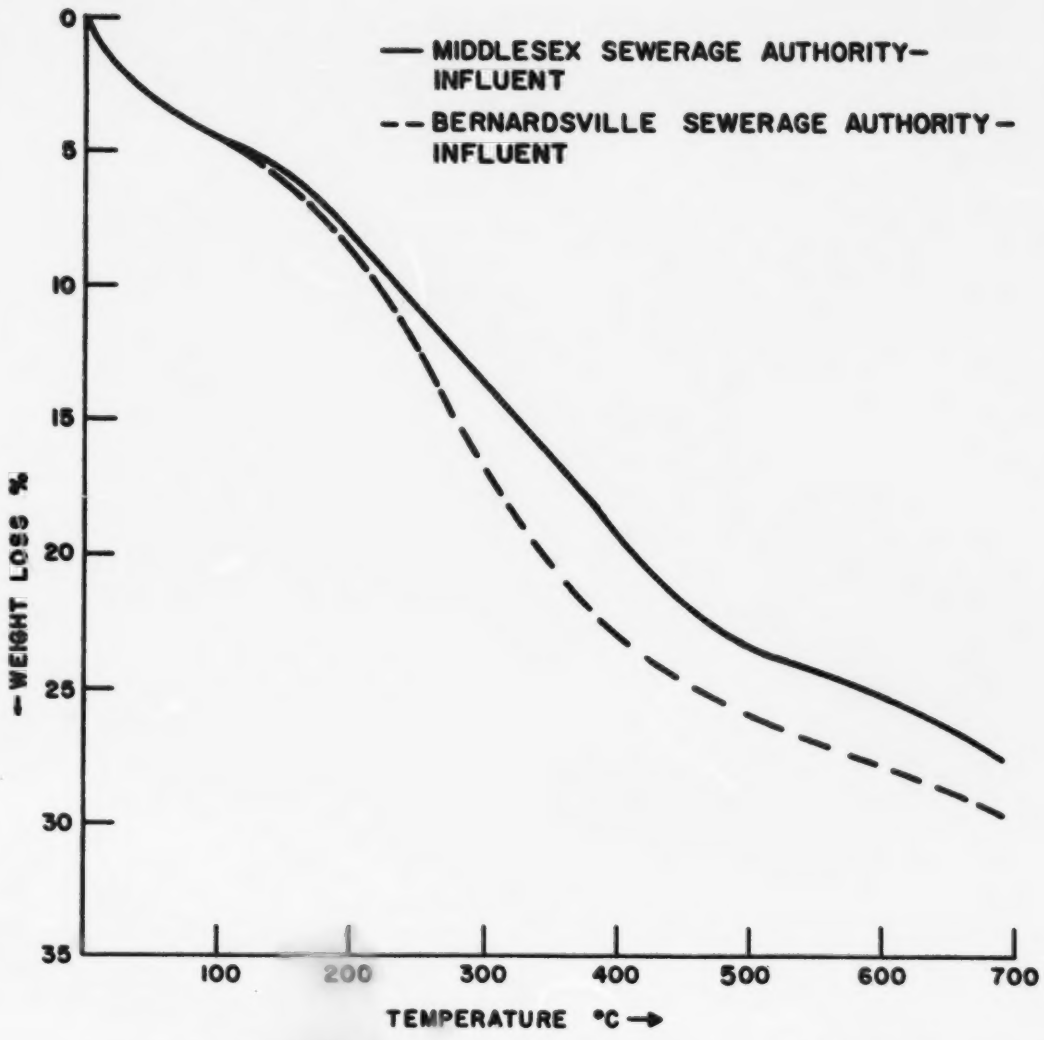

FIGURE 8 - THERMOGRAVIMETRIC ANALYSIS OF DISSOLVED SOLIDS IN BERNARDSVILLE AND MIDDLESEX INFLUENT.

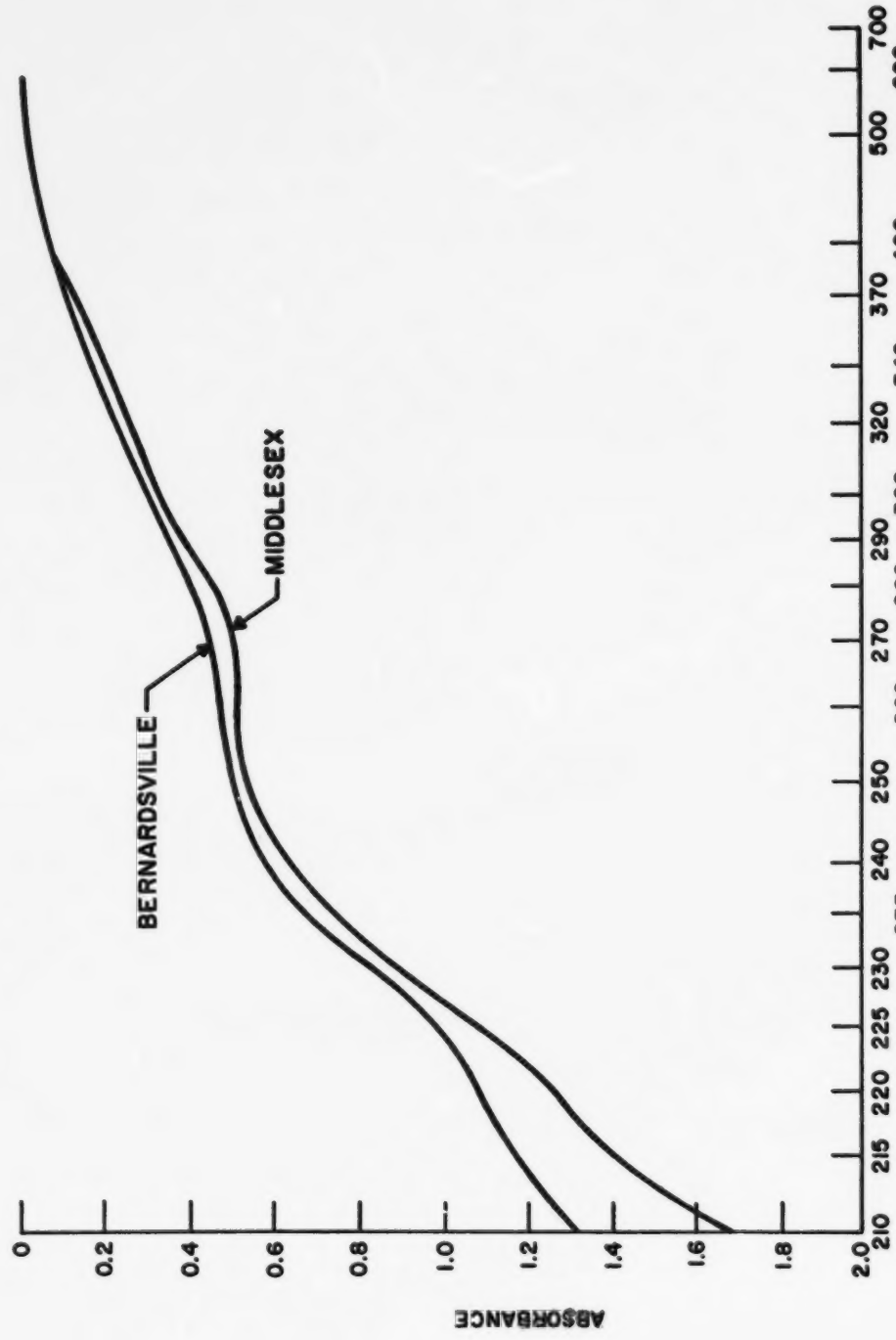

FIGURE 9 - ABSORPTION SPECTRA OF INFLUENT FILTRATE

TABLE 4

THE EFFECT OF SOLID DEPOSITS ON POLARIZATION RATIO AND TOTAL BACK-SCATTERED LIGHT

Date Influent Collected	Time Beaker Submerged	Polarization Ratio			Total Backscattered Radiation (mv)		
		Before Cleaning	After Cleaning	% Change	Before Cleaning	After Cleaning	% Change
8/19/69	42 hours	.569	.570	0	3.116	3.118	0
8/25/69	6 days	.421	.421	0	6.485	7.000	7.5
8/25/69	8 days	.422	.421	0	3.935	6.670	40.8
9/16/69	1 month	.435	.432	0*	0.464**	0.504**	9.0

* Within experimental error

** The low detector voltage with the beaker submerged for one month, both before and after cleaning, was the result of an optical readjustment; the width of the incident beam was reduced in anticipation of a large solids buildup on the beaker's surface. Studies with artificial deposits had indicated that a large surface buildup could introduce error in the measurement. Reducing the width of the incident beam eliminated this problem.

intensity of backscattered radiation measured through the deposited solids was reduced 7.5 per cent. The polarization ratio measurement was not affected. This was also found to be the case for the beaker submerged for eight days. A 40.8 per cent reduction in intensity of the backscattered radiation was observed, but the polarization ratio was still unaffected by the deposited solids.

Visual examination of the beaker submerged for one month indicated less of a solids buildup than was observed after eight days. The total backscattered radiation was reduced only 9 per cent (see Table 4). The polarization ratio was again unaffected by the solids buildup. Solids build-up on the optical surfaces apparently do not influence the depolarization measurements because the $E_{\perp}$ and $E_{\parallel}$ components in the backscattered radiation are combined into a ratio. Since both components are equally attenuated by scattering when the backscattered radiation passes through the buildup. The effect of this attenuation is cancelled by the use of a ratio.

Flow Velocity

A gravity flow system was designed and built in the laboratory, and used for depolarization measurements on flowing sewage. The system consisted of two 55 gallon drums, one above the other. Opening a ball valve allows the fluid to flow from the upper to the lower drum through a clear 3 inch diameter plastic test section. The diameter was selected to achieve as high a flow rate as possible with an optical path length which will permit accurate measurements of the polarization ratio.

A comparison of polarization measurements on static and flowing sewage samples indicates that the polarization ratio is unaffected by flow. Little difference in polarization ratio was exhibited by the static and flowing of Middlesex influent (see Table 5). The fluctuations in the initial measurement of polarization ratios for the flowing sample was caused by settling of suspended solids. In the two-chambered gravity flow system used in the experiments, the liquid was static in the upper reservoir until released to flow through the test section into the lower chamber.

TABLE 5

FLOW vs. POLARIZATION RATIO

Polarization (Static)	With Orifice			Without Orifice		
	Time (Sec.)	Flow Rate (ft/sec.)	Polarization Ratio	Time (Sec.)	Flow Rate (ft./sec.)	Polarization Ratio
0.634	2	1.8	0.643	0	17.9	0.619
	30	1.8	0.654	1	17.1	0.649
	45	1.8	0.650	2	16.3	0.663
				3	15.5	0.653
				4	14.8	0.642
				5	14.0	0.626

SECTION VI

DESIGN OF FIELD MODEL

Submerge Unit

The optical and mechanical portion of the suspended solids monitor is composed of two basic units separated by a light baffle, the light source and the light sensor sections (see Figure 10). The light source section consists of a Zeiss microscope lamp operated at 22 watts. The polarized light is mechanically chopped at the rate of 1 cycle per second. The chopped light is then passed into the sewage environment through a quartz window. The receiving unit consists of a beam splitter, two analyzers, two condensor lenses and a closely matched pair of photodiodes. The receiving stage is constructed so that the $E_{\perp}$ and $E_{\parallel}$ components are measured simultaneously. The outputs are conditioned electronically to provide a measure of the degree of depolarization $E_{\perp} / E_{\parallel}$. The sum of $E_{\perp}$ and $E_{\parallel}$ is also obtained electronically. This measures the absorption of light by colored particles and lightsource aging, and indicates when cleaning the window or light-bulb replacement is necessary.

To prevent stray light from passing tothe receiver stage, a light shield is placed between the source light stage and the receiver stage. These units are housed in a case (see Figure 11) which was constructed with a water tight lid using an "O" ring seal. Electrical connections to the light source unit and the optical receiving unit are brought into the watertight container through two bulkhead connectors located at the lower rear section of the watertight container. To insure complete tightness, latex rubber hoses are pulled over the cables and secured by clamps to the bulkhead connectors. Division of the cables avoids any AC field being superimposed on the low-level detector signals.

Electronic System

The detector and electronic parts of the suspended solids monitor consist of two light sensors, two preamplifiers with independent power supply, a photocell light system, a synchronizing pulse circuit, a logic circuit, two amplifier channels providing integration and subtraction of signals, a sum and ratio readout circuit and a power supply. (A circuit diagram is available from the authors upon request).

The light sensors for detecting the orthogonally polarized components of backscattered radiation are PIN 267 A photodiodes operated in the photovoltaic mode.

The outputs of the detectors are connected to two identical DC

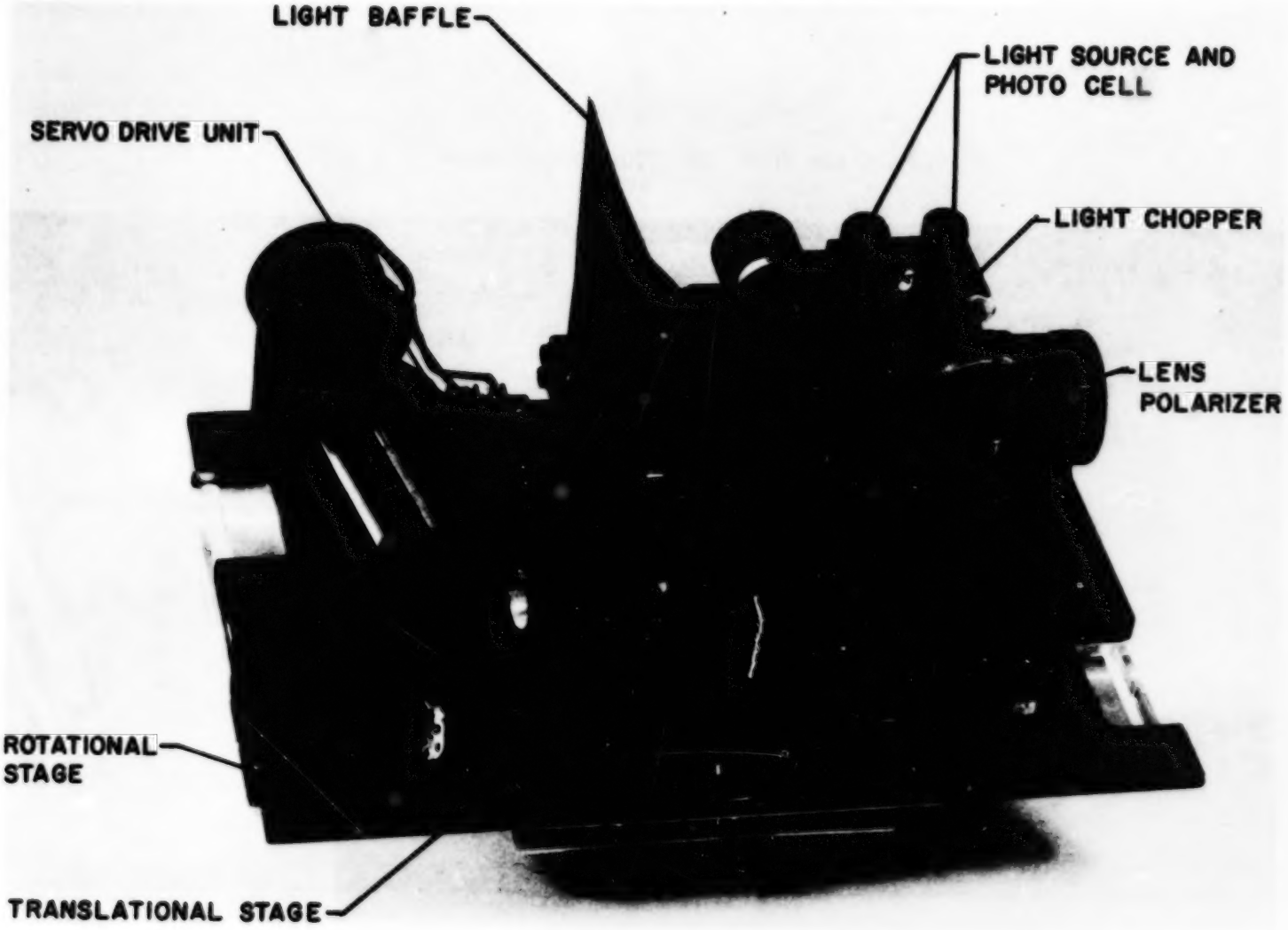

FIGURE 10 - OPTICAL AND MECHANICAL COMPONENTS OF SUSPENDED SOLIDS MONITOR

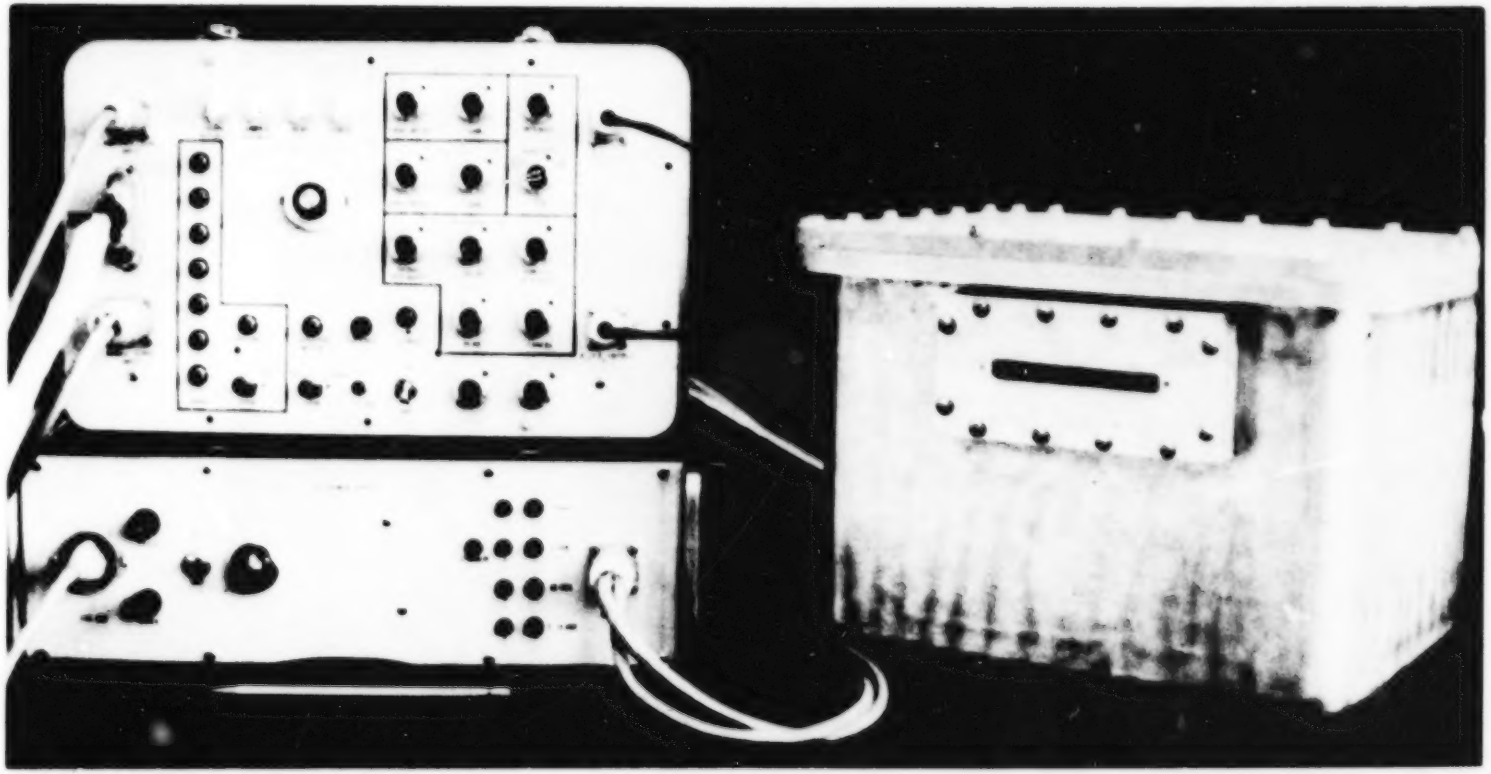

FIGURE 11 - DEVELOPMENTAL SUSPENDED SOLID MONITOR SYSTEM

preamplifiers powered by their own dual power supply. These amplifiers were chosen for low drift and differential output. The output of the preamplifiers are routed through instrumentation cable to the control station, from the submersible housing (see Figure 11).

Control Station

The buffer amplifiers and the remaining electronics are located in the control station (see Figure 11). The negative-going signals from the preamplifiers are applied through 51-ohm resistors to the inverting inputs of the buffer amplifiers. Gain, adjustable from zero to 100, is provided at this point to adjust for differences in the sensitivity of the diodes and mismatch of the optical beams. Variable $\pm$ 150 mv offsets are provided to compensate for drifts of the preamplifiers in the submersible unit.

A small light projects a beam at the driving gear of the chopper assembly (see Figure 10). A gold foil mirror is mounted on the chopper to reflect a beam from the light source into a photocell to produce a synchronization pulse. The output of the photocell triggers a fixed 25-volt, positive-going pulse of 50 milliseconds duration. The pulse synchronizes the logic circuits with the rotating chopper.

The logic consists of a network of five pulse generators which produce 5-volt pulses of adjustable duration to operate the electronic sample-and-hold switches needed for integration, readout, and cancellation. Each of the two channels contains two integrators, to measure background signal due to ambient light and total signal with the chopped light added.

After integration of signal plus ambient and ambient, the two are subtracted at the difference amplifiers. The output of each channel is applied to the sum amplifier and divider module. After readout, the integrators are reset to zero for the next cycle. The sum amplifier has a scale-adjusting potentiometer for calibration. The ratio divider has no external adjustments and is accurate to $\pm$ 1 percent.

SECTION VII

FIELD EVALUATION

Sewage Source

The field evaluation of the developmental suspended solids monitor was carried out in the combined sewage influent and in the effluent of the Perth Amboy, New Jersey Sewage Treatment Plant. This plant is subject to storm drainage and industrial waste as well as sanitary sewage and therefore provides a wide range of composition.

Sources of Experimental Scatter

The polarization ratio was found to decrease in a regular manner with the weight concentration of suspended solids in both the influent and effluent (see Table 6, Figure 12 and Figure 13). The different points in these figures represent samples collected at different times. Replotting the data in Figure 12 according to Equation 5 (page 6), reveals a linear relationship between Log P and concentration with a zero intercept (see Figure 14).

The measured polarization ratio can be related to the concentration of suspended solids only within the reproducibility of the gravimetric determinations. A spread of as much as 20 percent was encountered in gravimetric measurements on three samples collected within a period of minutes, while a maximum range of only 11 percent in degree of depolarization was encountered in the same period of time.

Lack of precision in gravimetric determinations could be caused by limited sample volume. Because of the length of time required for filtration, samples were restricted to 50 ml. Another source of error could lie in the sampling procedures used. Comparison of a continuous readout from the suspended solids monitor with the gravimetric determination of suspended solids concentration requires samples that are representative of that to which the monitor is continuously responding. In field evaluation of the instrument, a grab sampling technique was used which could lead to considerable scatter of the results. An open sampling cup was dipped into the sewage and filled at the level of the optical window. On withdrawal it passed upward through the sewage surface, thus changing composition especially in the presence of oil or other floating matter.

Periodically there was an influx of heavy oil into the influent and a carryover into effluent. The relationship between the polarization ratio and concentration of suspended solids as measured in the presence of heavy oil contamination is shown in Figure 13. Replotting the results in Figure 13 according to Equation 5 reveals that a linear relationship exists between Log P and concentration but this relation-

TABLE 6

FIELD EVALUATION DATA FOR DEVELOPMENTAL

SUSPENDED SOLIDS MONITOR

Date of Measurement	Medium	Polarization Ratio	Average mg/l Solids (Gravimetric)	Range in mg/l (Gravimetric)	Log Polarization Ratio	Comments
8/14/70	Influent	0.466	165	164-167	-0.332	
8/14/79	"	0.417	208	196-220	-0.380	
8/17/70	"	0.514	197	186-208	-0.289	SO_2 gas,some oil
8/17/70	"	0.441	184	174-194	-0.356	
8/17/70	"	0.396	219	208-230	-0.403	oil bubbles
8/17/70	"	0.376	231	228-236	-0.424	
8/18/70	"	0.338	245	238-252	-0.471	
8/18/70	"	0.358	220	210-230	-0.446	
8/18/70	"	0.332	369	344-393	-0.479	heavy oil
8/19/70	"	0.408	269	258-280	-0.386	heavy oil
8/19/70	"	0.370	319	308-324	-0.432	
8/20/70	"	0.365	269	246-286	-0.438	oil
8/20/70	"	0.325	247	240-258	-0.488	
8/21/70	"	0.446	357	332-382	-0.350	emulsion formed, affected gravimetric det., improper sampling
8/21/70	"	0.377	225	218-240	-0.424	
8/21/70	"	0.365	261	234-278	-0.438	
8/25/70	Effluent	0.555	206	198-219	-0.256	oil
8/25/70	"	0.518	208	198-215	-0.286	oil
8/25/70	"	0.493	225	224-226	-0.307	oil
8/25/70	"	0.483	218	-	-0.314	oil
8/25/70	"	0.389	207	200-216	-0.311	oil
8/27/70	"	0.453	174	171-181	-0.344	
8/27/70	"	0.438	171	166-179	-0.358	
8/27/70	"	0.362	163	160-167	-0.441	
8/27/70	"	0.340	149	148-150	-0.468	soap suds,affected grav. det.

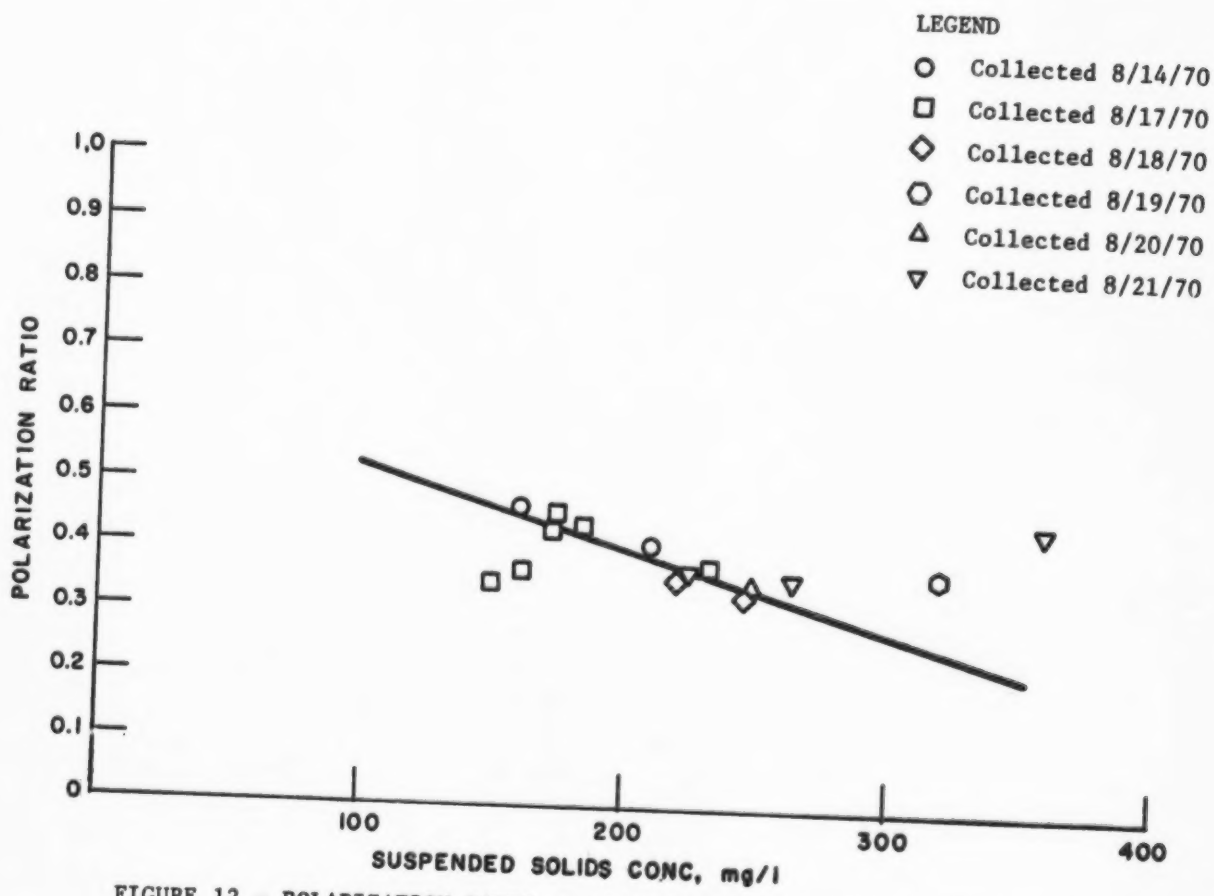

FIGURE 12 - POLARIZATION RATIO vs GRAVIMETRIC SUSPENDED SOLIDS, MEASUREMENT PERTH AMBOY SEWAGE TREATMENT PLANT.

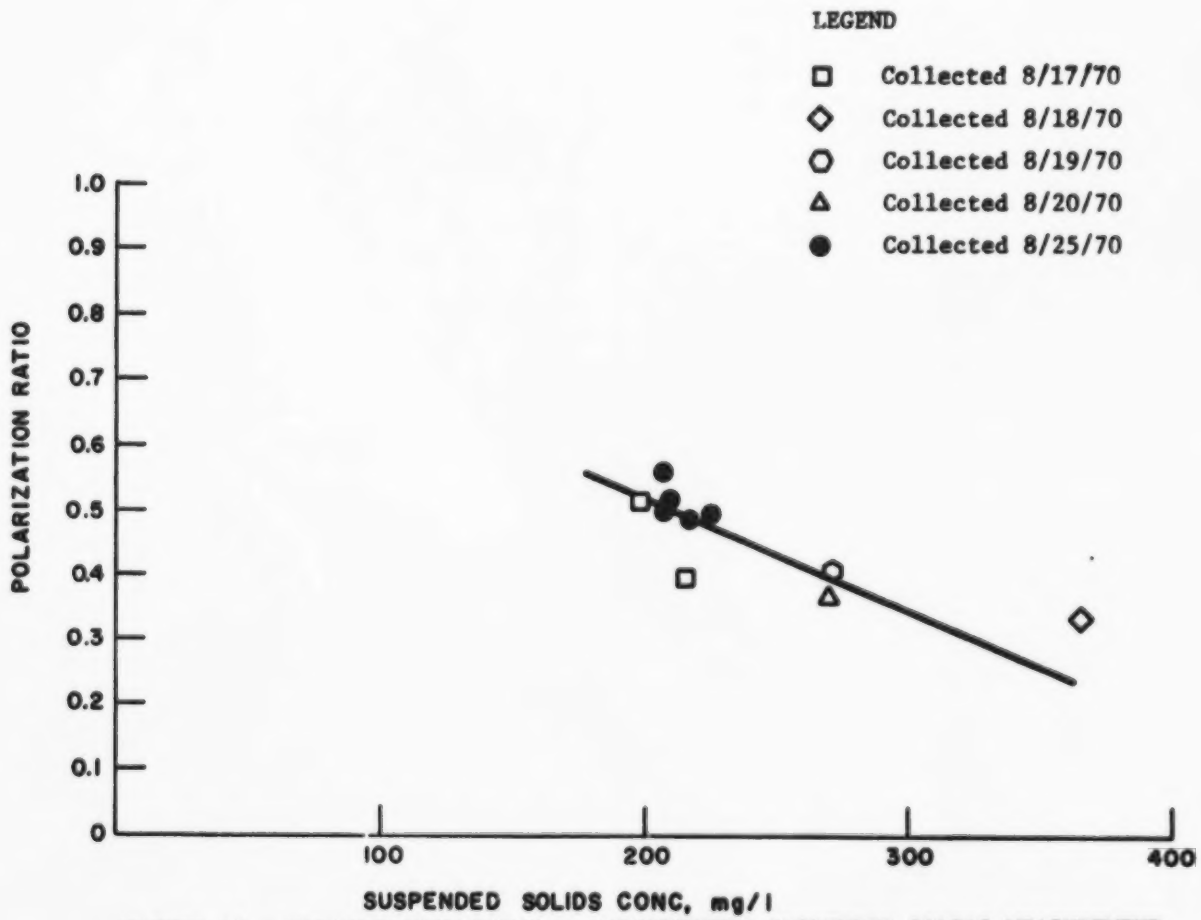

FIGURE 13 - POLARIZATION RATIO vs GRAVIMETRIC SUSPENDED SOLIDS MEASUREMENT, PERTH AMBOY SEWAGE TREATMENT - HEAVY OIL CONTAMINATION.

ship is displaced to the right of the relationship obtained when the samples were free of oil contamination (see Figure 14). Predictably, the suspended solids monitor does not respond to the oil on water surface which is inadvertantly collected and appears as weight in the gravimetric measurements. Calculations indicate that when heavy oil was present, an increase of about 30 percent in weight of solids was found by gravimetric measurements.

Effect of Ambient Light

Measurements on the effluent were performed to determine whether the ambient radiation resulting from sunlight would influence the results. Sunlight had no affects on the results obtained with the monitor, provided that the quartz window was located approcimately 18 inches below the surface of the Perth Amboy effluent. The instrument was positioned for three days in an open channel which carried the effluent from the clarifiers to the chlorination chamber. Large amounts of oil were present in the effluent for two days. The results obtained during the time agree with the relationship established earlier between degree of depolarization and concentration of solids when oil is present (see Figure 14). The data obtained on the third day, in the absence of oil, agreed well with the relationship previously established when no oil was present.

Discussion

The development program under the present contract was terminated by exhaustion of resources and by the contractor's change of corporate policy leading to discontinuation of instrument development work. The present development model was tested as described herein; but with additional resources, it would be useful to conduct a more extensive program of evaluation and data collection.

Present Status of the Suspended Solids Monitor Development

Badger Meter Inc., Precision Products Division, Tulsa, Oklahoma, has designed and is presently constructing a second generation suspended solids monitor under subcontract to Onondaga County, New York, USEPA Grant No. S-802400 (11020 HFR). They have developed a submersible package which is a small fraction of the size of the submersible portion of the developmental suspended solids monitor described in this report. A linear readout over the concentration range from 10 mg/l to 100,000 mg/l has been achieved in the laboratory on model hydrosols using this second generation submersible unit.[5]

A commercial model should be available from Badger Meter by late 1974. Its price is estimated to be about $1,500.

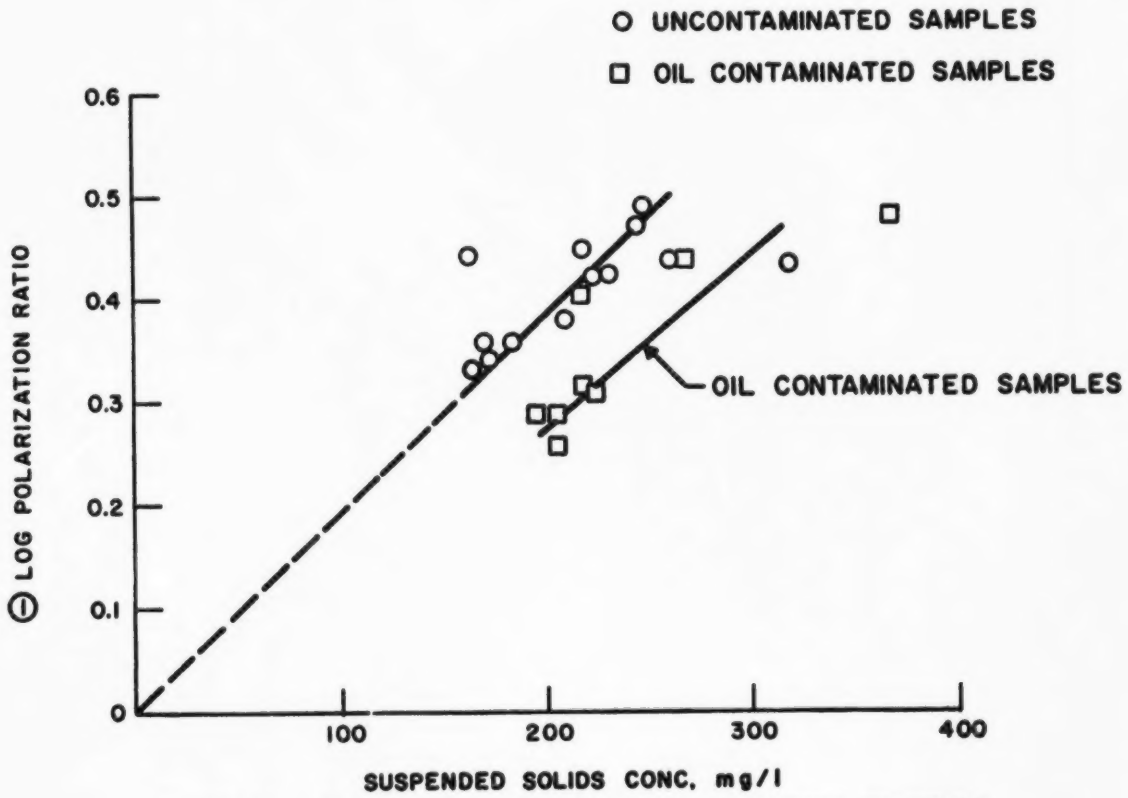

FIGURE 14 - LOG POLARIZATION RATIO vs GRAVIMETRIC SUSPENDED SOLIDS MEASUREMENT, PERTH AMBOY SEWAGE TREATMENT PLANT.

SECTION VIII

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4. Oster, G., Chemical Review, 43, 347 (1948).

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2. Liskowitz, J. W. and Franey, G. J., Environ. Sci. Technol., 6, 43, 1972.

3. U. S. Patent 3,600,094 Suspended Solids Concentration Measurement Using Circular Polarized Light.

4. U. S. Patent 3,612,688 Suspended Organic Particles Monitor Using Circularly Polarized Light.

5. U. S. Patent 3,612,689 Suspended Particle Concentration Determination Using Polarized Light.

6. U. S. Patent 3,653,767 Particle Size Distribution Measurement Using Polarized Light of a Plurality of Wavelengths.

SECTION X

APPENDIX

Gravimetric Procedure

The equipment needed in this project for the gravimetric determination of suspended solids in sewage is as follows:

1. Three or more Pressure Filtration Funnels, Gelman Type 4280.
2. Two-stage regulator with a delivery pressure of 200 lb/in^2.
3. 1A Cylinder of Nitrogen.
4. Necessary valves and tubing to allow applying and relieving pressure to funnels.
5. Supply of 10μ and 0.3μ filters such as Gelman Type Polypropylene 10M and GA-70-3M.
6. Supply of plastic petri dishes for filters, available from Millipore Filter Corporation.
7. Analytical balance with 0.1 mg sensitivity.
8. Duckbill forceps for handling filters.
9. Sampling scoop for obtaining sample in front of the suspended solids monitor.
10. Vacuum oven for drying samples.
11. 50 ml graduated cylinder and misc. glassware.

The equipment is used as follows:

1. Preweigh the filters and store in petri dishes - record weights.
2. Disassemble filter funnels and position 10μ filters in base.
3. Screw sleeve into base.
4. Take a 500-1000 ml sample of sewage in front of monitor while recording ratio.
5. Mix sample thoroughly and measure out 50.0 ml into graduated cylinder.
6. Pour sample from cylinder into filter assembly.
7. Secure filter assembly to pressure head.

8. Position a beaker below outlet of filter.
9. Apply pressure.
10. When the filtration is complete, relieve pressure and disassemble filter.
11. Remove the 10μ filter with forceps. Store in its petri dish.
12. Position 0.3μ filter in base.
13. Screw sleeve into position.
14. Pour the filtrate from the beaker to the assembly.
15. Secure filter assembly to pressure head.
16. Position the beaker below outlet of filter.
17. Apply pressure.
18. When the filtration is complete, as evidenced by bubbles coming from the outlet of the funnel, relieve pressure and disassemble filter.
19. Remove the 0.3μ filter with forceps and store in its petri dish.
20. Dry the samples overnight at 60°C and 20" Hg in the vacuum oven.
21. Remove the dried samples from the oven and cool for 5-minutes.
22. Weigh the filters to within $\pm$ 0.1 mg.
23. Compute the sample weight by subtracting the tare weight of the filter.